FINAL PROJECT REPORT

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"PHYTOPLANKTON BLOOMS AND COASTAL PHYSICAL PROCESSES"

Submitted to the Office of Naval Research

by

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Goals and Objectives

The overall goal of our study was to gain understanding of the modes by which the physics of coastal regions couple with biological processes to create mesoscale enhancements of phytoplankton production. We attempted to identify the influence of various types of circulation (e.g. wind-driven, buoyancy-driven, tidally-driven) on phytoplankton bloom dynamics and size structure in the southwestern Gulf of Maine. Specifically, we focused on the mechanisms regulating post spring-bloom production in the coastal boundary layer (around 10 km from the coast). This involved investigations of the scales of patchiness of individual phytoplankton populations in this region, with initial emphasis on dinoflagellates.

Approach

To achieve our objectives, we performed extensive field surveys in the southwestern Gulf of Maine during the bloom season (April to August). Physical measurements obtained with a CTD/transmissometer system, and biological measurements obtained with a hose-pumping system or discrete water bottle sampling, were made approximately weekly during the field season. Sampling cruises giving dense vertical resolution were interspersed with additional cruises which gave extensive horizontal coverage. Auxiliary data sets such as stream flow, wind data and satellite images were obtained to aid in interpretation of the hydrographic and biological data. We also made use of near real-time capabilities for the remote sensing of sea surface temperatures (SST) using NOAA's Coastwatch satellite system. This allowed an efficient, interactive approach to sampling in which we were able to rapidly respond to features of SST that we believed could affect the distribution of the dinoflagellates.

Tasks Completed

During the 1989 fiscal year, we formulated a conceptual model of alongshore transport of phytoplankton populations in the southwestern Gulf of Maine based on data from the 1988 field season. We then tested this model in the field with strategically-timed cruises from 1989 through the 1991 field seasons. The data supported the model very well and resulted in numerous publications (Franks et al., 1989; Franks and Anderson, 1989, 1991a,b; Anderson and Keafer, 1992; Keafer and Anderson, 1993). Additionally, a joint cruise effort was initiated with Bob Beardsley of the WHOI Physical Oceanography Department where we sampled further offshore in 1991 than in prior years. searching for a previously-seen sub-thermocline water mass that may be coupled to the transport mechanisms we have described within the surface waters.

Scientific Results

Our results indicate that dinoflagellate populations are largely controlled by buoyancy currents created by riverine inputs along the southwestern coast of the Gulf of Maine. Diatom populations appear to dominate offshore of the front formed by the buoyancy current. The buoyancy plumes advect the dinoflagellate populations hundreds of kilometers along the coast, with the degree to which these plumes are compressed nearshore or spread into thin layers extending well offshore being determined by coastline shape and local wind stress. The patchiness of the dinoflagellate populations show different cross- and alongshore scales which appear to be determined by the physical dynamics.

An important observation from the 1990 field season was that the buoyant plume and its associated phytoplankton population were apparently transported along the coast into Massachusetts Bay and then well offshore, far from the plume's nearshore initiation site in southern Maine waters (Fig. 1). Transit time of the plume was rapid across Massachusetts Bay and further offshore onto Georges Bank, an area rich in offshore fisheries resources. In contrast, the late spring 1991 conditions of relatively low river flow and persistent coastal upwelling caused by winds predominantly from the south/southwest pushed the plume and its associated phytoplankton offshore and prevented the "normal" movement of the population further south out to Georges Bank. These results are consistent with our conceptual model, which was formulated to account for different meteorological conditions.

Accomplishments

The main accomplishments of our work has been the elucidation of following mechanisms:

— Alongshore transport of phytoplankton populations in the southwestern Gulf of Maine.

Although we have focused on dinoflagellates, it is clear that this major hydrographic feature has a profound effect on spring populations of the other phytoplankton species and organisms higher in the food chain.

In addition, we established the scales of patchiness over a wide geographic area, and are beginning to understand and formulate simple models of the mechanisms creating that patchiness.

ONR-Sponsored Publications

The results of this work have been disseminated through publications in the open literature as well as by posters and oral presentations at scientific conferences. In the following listing P = published paper, IC = invited contribution, C = contributed paper, and R = technical report.

P - Franks, P.J.S. and D.M. Anderson. 1989. Sampling coastal dinoflagellate blooms: equipment, strategies and data processing. **In:** G. Hallegraeff and J.L. McLean (eds.), *Biology, Epidemiology, and Management of Pyrodinium Red Tides* ICLARM Conf. Proc. 21, Manila, Philippines. pp. 235-256.

P - Franks, P.J.S., D.M. Anderson and B.A. Keafer. 1989. Fronts, upwelling, and coastal circulation: Spatial heterogeneity of *Ceratium* in the Gulf of Maine. **In:** T. Okaichi, D. M. Anderson and T. Nemoto (eds.), *Red Tides - Biology, Environmental Science, and Toxicology*. Elsevier, N.Y. pp.153-156.

P - Franks, P.J.S., 1990. Dinoflagellate blooms and physical systems in the Gulf of Maine Ph.D. Thesis. MIT/WHOI, WHOI-90-23.

P - Franks, P.J.S. and D. M. Anderson. 1992a. Alongshore transport of a phytoplankton bloom in a buoyancy current: *Alexandrium tamarense* in the Gulf of Maine. Mar. Biol. **112:** 153-164.

P - Franks, P.J.S. and D. M. Anderson. 1992b. Toxic phytoplankton blooms in the southwestern Gulf of Maine: Testing hypotheses of physical control using historical data. Mar. Biol. **112:** 165-174.

P - Franks, P.J.F. Phytoplankton blooms at fronts: patterns, scales, and physical forcing mechanisms. Rev. Aquat. Sci. **6:** 121-137.

P,C - Franks, P.J.S. Sink or swim: Accumulation of biomass at fronts. AGU Annual Fall Meeting. December, 1990. San Francisco, CA. Mar. Ecol. Prog. Ser. **82:** 1-12.

P,C - Keafer, B.A. and D.M. Anderson. 1993. The use of remotely-sensed sea surface temperatures in studies of *Alexandrium tamarense* bloom dynamics. **In:** T. J. Smayda and Y. Shimizu (eds.), *Toxic Phytoplankton Blooms in the Sea*. Elsevier, Amsterdam, pp. 763-768.

PI - Franks, P.J.S. and D. M. Anderson. Growth and diffusion of a phytoplankton bloom: a simple model of *Ceratium longipes* in the Gulf of Maine.

IC - Franks, P.J.S. Dinoflagellate blooms: patterns, scales, and forcing mechanisms. *Proceedings of the Fourth International Conference on Modern and Fossil Dinoflagellates*. Marine Biological Laboratory, Woods Hole, MA. May, 1989.

IC - Keafer, B.A. and D.M. Anderson. Toxic Algae in Massachusetts Bay: in situ growth or advection? Estuarine Eutrophication Symposium/New England Estuarine Research Society. Annual Fall Meeting October 25, 1990, Newport, R.I.

C - Franks, P.J.S. Alongshore transport of a toxic dinoflagellate bloom. AGU/ASLO Annual Ocean Sciences Meeting. February 12-16, 1990. New Orleans, La.

C - Anderson, D.M. and B.A. Keafer. Bloom dynamics of *Alexandrium tamarense* in the southwestern Gulf of Maine. Poster Session. Fifth International Conference on Toxic Marine Phytoplankton. October, 1991, Newport, RI.

R - Anderson, D.M. and B.A. Keafer. 1992. Paralytic shellfish poisoning on Georges Bank: In situ growth or advection of established populations? **In:** J. Wiggin and C.N.K. Mooers (eds.), *Gulf of Maine Scientific Workshop Report*, Woods Hole, MA. Jan. 8-10, 1991, Urban Harbors Institute, University of Massachusetts, Boston, MA. pp. 217-224.

Statistics:

5 Papers published, refereed journals
1 Paper submitted, refereed journal
3 Books or chapters published, refereed publications
1 Ph.D. thesis
0 Books or chapters submitted, refereed publication
2 Invited presentations
4 Contributed presentations
1 Technical report and papers, non-refereed journals
0 Undergraduate students supported
1 Graduate student supported
0 Post-docs supported
1 Other professional personnel supported

EEO/Minority Support

0 Female graduate students
0 Minority graduate students
0 Asian graduate students
0 Female post-docs
0 Minority post-docs
0 Asian post-docs

Patents and Awards:

University Corporation for Atmospheric Research (UCAR) Postdoctoral Fellowship for Ocean Modeling - awarded to Peter J. S. Franks at the conclusion of his dissertation work on this project. Franks is now an Assistant Professor at Scripps Institution of Oceanography.